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Discovery

Sustainable and smart materials in Geotechnical constructions

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ABSTRACT
Innovation in technology requires judicious consideration of cost saving, disaster mitigation capability and its environmental impact. This paper describes some of the environmentally friendly cost effective technologies born in Japan in the last two decades. The materials used in those techniques are scrap tires and tire derived geomaterials. Few ground improving/stabilizing techniques using tire derived products for geotechnical applications in Japan are introduced here. Descriptions and validations through model testing, field testing as well as case study applications of some of those techniques are described.

Keywords: cost reduction, disaster mitigation, sustainability, waste tires, tire chips, tire shreds

1. INTRODUCTION
Present day geotechnical engineers face many challenging issues arising out of the climate change-induced disasters. Formidable amongst them is how to reduce costs for construction practices intended to mitigate disasters, and at the same time minimizing the environmental impacts. Therefore, developing techniques and materials that satisfy engineering effectiveness, eco-friendliness, and cost savings are major challenging tasks for geotechnical engineers. Few examples of eco-friendly multiple adaptive measure for protecting water fronts under severe external forces induced in the context of climate change are described in Yasuhara et al. (2016).

On the other hand, last two decades show the emergence of many environmentally friendly sustainable construction practices using scrap tires. Many new techniques using materials derived from scrap tires (Fig. 1) have been developed in Japan (Hazarika et al., 2009b; Hazarika et al., 2010b; Yasuhara et al., 2006). Scrap tires and scrap tire derived materials (granulated rubber, tire chips, tire shreds, etc.) are new geomaterials, which have been gaining popularity amongst the geotechnical engineers because of their non-dilatant nature (Hazarika, 2013). Such tire derived geomaterials (TDGM) have been receiving worldwide attention also largely because of their potential economic and environmental benefit. They are sustainable construction materials because thermal recycling (burning the tires for generating energy) of scrap tires releases four times more CO_2 to the atmosphere than that of recycling those as materials. Advantages of using such materials in geotechnical engineering practices are manifold. They are lightweight, have high vibration absorbing capacity, and have high elastic compressibility. They also have high hydraulic conductivity because of their granular nature. In addition, they possess a very good thermal isolation potential. Lastly, they are non-dilatant materials, which make them popular as ground improving materials. Due to those special characteristics, these emerging and sustainable materials were coined *smart geomaterials* by Hazarika (2007).

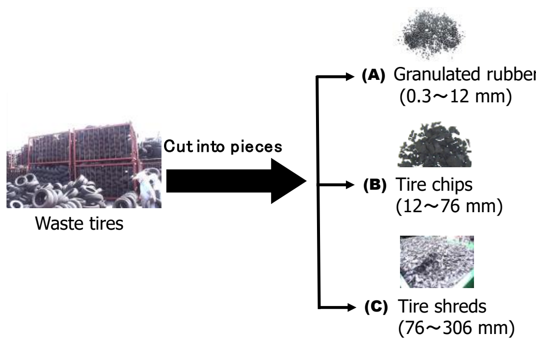


Figure 1 Tire-derived geomaterials

A comprehensive collection of papers on recent researches and applications worldwide can be found in Hazarika and Yasuhara (2007) that includes the state of art reports by Edil (2007), Humphrey (2007) and Yasuhara (2007). Varieties of other geotechnical engineering applications of tire chips and tire shreds have been reported elsewhere (Bosscher et al., 1997; Tweedie et al., 1998; Humphrey and Tweedie, 2002). This paper describes some of the novel ground improvement as well as construction techniques developed/practiced in Japan using materials derived from scrap tires.

2. FEW JAPANESE EXPERIENCES OF WASTE TIRE APPLICATIONS

Applications for utilizing the tire-derived geomaterials can be broadly classified into two categories: (1) stand-alone application (use of tires and tire shreds/tire chips as it is) and (2) composite application (tire shreds/tire chips mixed with soils and/or other materials). Both applications have many potential benefits. Amongst those possible techniques of utilizing the scrap tires, this paper introduces few ground improving/stabilizing techniques for geotechnical applications in Japan. The following are few applications which are described: (1) use of whole tires in embankment, land reclamation and sea wall protection (stand-alone and composite applications), (2) use of tire shreds to improve the drainage (stand-alone application), (3) use of tire chips as compressible inclusion (stand-alone applications), (4) use of tire chips cushion and drains to mitigate the earthquake related damage (stand-alone applications), (5) use of sand/gravel mixed tire chips layer to mitigate the earthquake related damage (composite application), and (6) use of ductile tire chips mixed cement treated clay in waste disposal barrier (composite application). The techniques, model testing as well as case study applications of some of those are described in the following.

3. STAND ALONE APPLICATIONS

3.1. Tire Retaining Wall

The 2011 off the Pacific Coast of Tohoku Earthquake and the record breaking tsunami that easily overtopped many coastal structures, brought devastating damage to many geotechnical structures in the eastern coast of Tohoku area, Japan (Hazarika, 2011a; Hazarika et al., 2012a; Hazarika et al., 2012b). While surveying the tsunami disaster areas immediately after the disaster, the first author discovered a retaining wall (made of recycled tires) that miraculously survived the tsunami disaster in Okirai area, Iwate prefecture, Japan (Fig. 2). Ironically, this tire retaining wall is located just about 150 m away (towards the land) from a completely collapsed sea wall (Fig. 3). The factory building situated on the backfill ground of the retaining wall was damaged by the tsunami,

and a natural slope nearby this tire retaining wall was eroded by the tsunami. According to some reliable sources, the wall was constructed about fifteen years ago. The fact that such low cost and sustainable structure, which was neither damaged by the earthquake nor by the inundation and scouring due to the tsunami is an excellent evident that such material can play a significant role in geotechnical disaster mitigation. A detailed study on the retaining wall based on field investigations and laboratory testing has been described in Hazarika et al. (2012c).

Figure 2 Survived tire retaining wall **Figure 3** Collapsed concrete sea wall

(Picture taken after the 2011 tsunami disaster)

3.2. Tire Embankment

Fig. 4a shows a monitored solid waste disposal site in the city of Noboribetsu, Hokkaido, Japan. Whole tires were used (Fig. 4b) in the slopes for the following purposes: (1) protect the geosynthetic liners from UV radiation, (2) protection from heaving of soils due to freezing, (3) reduce the load reduction from dumping truck and (4) vegetation. Approximately 238,000 waste tires were used in an area covering about 7,300 square km. As we can see from the figure that the shrubs inside the tires, which grow naturally during spring also add another benefit to using such materials.

(a) Slopes with geotextile liner (b) Same slope with whole tires

Figure 4 Solid waste disposal site in Noboribetsu, Hokkaido, Japan *(Courtesy: Shimizu Corporation, Japan)*

3.3. Tires in sea wall protection

To protect seawall from damage due to earthquake and tsunami, two measures need to be provided simultaneously: (a) protection of soils behind the seawall due to tsunami impact force and (b) protection of concrete cover behind the seawall due to force of backrush. A new technique to protect seawall from impact force of tsunami using waste tire structures behind seawall was developed by Hazarika and Fukumoto (2015) which is shown in Fig. 5. However, from aesthetic point of view, tire structures with filled soil on the back of a seawall is not appealing. Therefore, cultivation of suitable plants inside actual tires (used passenger car tires) was suggested towards creating a green surrounding. It is to be noted that saline soils generally exist along the coastline and barrier islands where sea water may enter, and collect in the soil (Appleton et al., 2009). Therefore, plants to be selected are such that they can sustain certain saline condition.

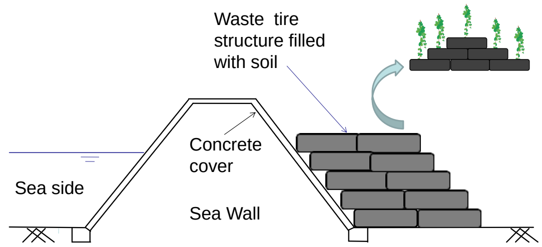


Figure 5 New concept of protecting seawall by using waste tire structure *(Hazarika and Fukumoto, 2015)*

Tsunami overflow test using model tires (Hazarika and Fukumoto, 2015) show that the tsunami impact force could be reduced considerably (Fig. 6) by placing filled tires (with a suitable filling material) behind sea walls to protect the damage of such structures from impact force and resulting scouring and erosion. Also, field test using actual tires and planting those using suitable plants showed that the greening effect could be maintained by planting trees inside the tires (Fig. 7). If implemented, this technique could be one of the effective methods for recycling of huge amount of waste tires. Selection of appropriate plants is key issue here so that the plants can survive in the saline conditions of soils that exist in coastal areas. Results of the field tests show that the filling materials of tires can be soils or tire chips mixed soils, and they do not have any significant effect on the growth of plants. However, appropriate percentage of tire mix in the soils is to be selected so that the strength of the tire structures are not affected, and at the same time plants growth are not endangered (Hazarika and Fukumoto, 2015).

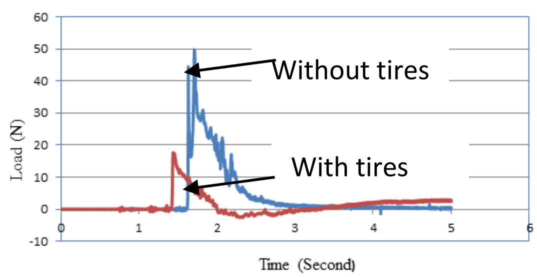


Figure 6 Impact force reduction capabilities of tires

(a) August 2014 (b) September 2014 (c) October 2014 (d) February 2015

Figure 7 Growth of plants inside tires

3.4. Cut Tires in Road Construction and Slope Protection

Many other applications of whole tires cut into two parts (Fig. 8) are described by Fukutake and Horiuchi (2007). They include protection of steep slope, earth pressure reduction against abutment, temporary access road construction after earthquakes and land reclamations, etc. As seen in the Figure, this kind of tire recycling involves use of whole tires as well as tire chips and tire shreds.

Figure 8 Multiple use of whole tires

3.5. Tires Shreds as Drainage Enhancing Materials

Tire shreds are highly permeable and hence are not vulnerable to clogging (Karmokar, 2007). A full-scale field trial on the use of tire shreds as drainage layer in a highway embankment was undertaken in Hokkaido, Japan (a site of East Nippon Expressway Co. Ltd. near Houbetsu east tunnel). Cross sectional view of the embankment where tire shreds drainage layers were installed is shown in Fig. 9. Design thickness of the blanket type drainage layer was set at 400 mm each with an inclination of 5% down toward the embankment face. Thickness of drainage layers were adjusted by considering the relevant consolidation of tire shreds. The design length and width of the tire shreds drainage layers were set to 40 m and 10 m, respectively. The target permeability coefficient was 10-1 ~ 100 cm/sec, which is equivalent to the permeability coefficient of gravel originally planned to be used in this field trial.

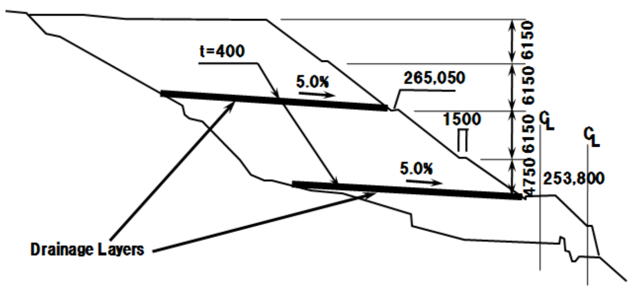


Figure 9 Cross sectional view of the embankment with tire shreds drainage layers (unit: mm)

(a) Construction stage (b) One year after the completion

Figure 10 Embankment during construction and after completion (Karmokar et al., 2007)

A total of 240 ton scrap tire shreds were used in the construction of the drainage layers. The construction steps involve the laying of tire shreds drainage layer using conventional equipment and machineries (Fig. 10a). A view of the embankment after one year of construction is shown in Fig. 10b. It is worthwhile mentioning here that the in-situ consolidations of tire shreds drainage layers were measured for about a year since their placement in the embankment (Karmokar, 2007; Karmokar et al., 2007), and the results were found to be conforming to the results of the consolidation tests conducted in laboratory. The level of in-situ consolidation at the bottom tire shreds layer was found to be 27%.

3.6. Tires Chips as Cushion

A novel Idea of using tire chips as compressible buffer was first introduced by Hazarika et al. (2010a). The technique is explained in Figure 11, where a lightweight and compressible tire chips layer sandwiched between the backfill and the retaining wall, can impart active state even to a non-yielding retaining wall.

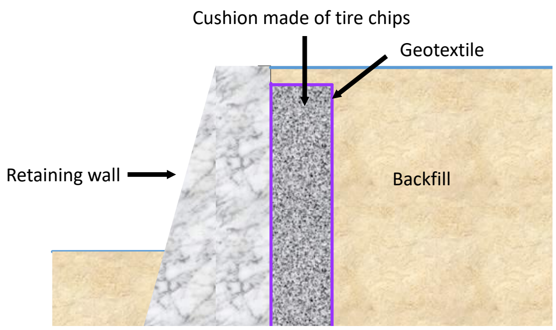
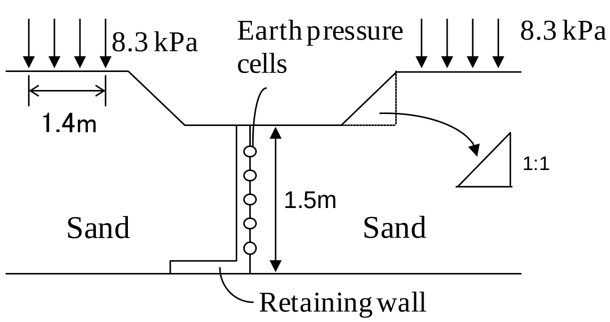
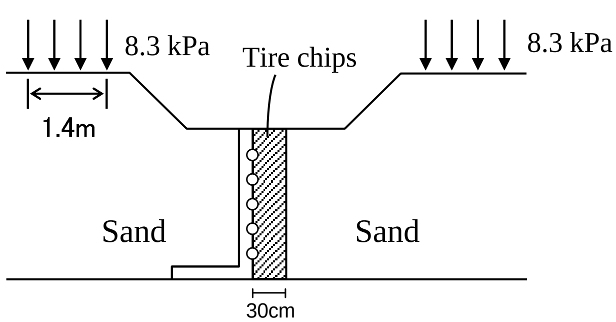


Figure 11 Tire chips as compressible buffer against rigid retaining wall (Hazarika et al., 2010a)



(a) Backfill with pure sand



(b) Backfill with tire chips cushion

Figure 12 Field test on tire chips as compressible buffer

Field tests were performed by Hazarika et al. (2010a) using a 1.5 m high rigid retaining wall against which the variation of static at rest pressure was measured for a week. The setup of the field tests are shown in Fig. 12. Fig. 13 shows the results of the tests (earth pressure distribution) for two conditions; conventional retaining wall and retaining wall with compressible buffer (thickness = 30 cm). It can be seen from the figure that the earth pressure is greatly reduced by using tire chips as buffer cushion. Kaneda et al. (2010) elucidated the mechanism of earth pressure reduction by such technique numerically, and their numerical simulation show that the static at rest earth pressure against the retaining wall could be brought to quasi-active state by using tire chips cushion sandwiched between wall and the backfill.

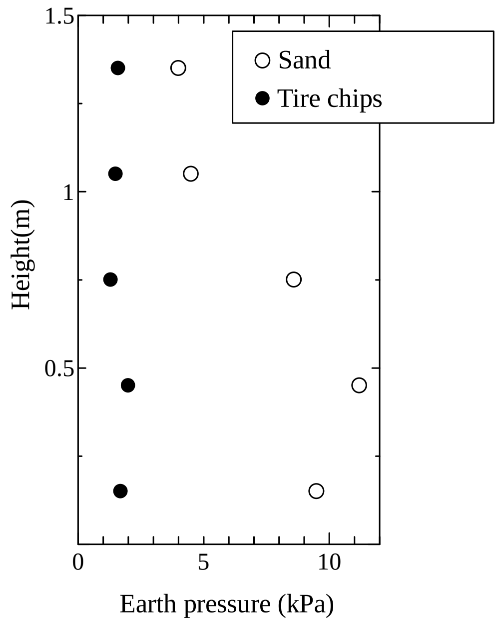


Figure 13 Results of the field tests

Hazarika (2007) developed a similar technique described above aiming at earthquake hazard mitigation of quay wall. The technique was named SAFETY (Structural Stability And Flexibility during Earthquakes using Tyres) and can minimize the structural hazard during earthquakes by exploiting the various potentials of tire chips (such as lightweight, compressible and ductile characteristics). Compressibility of tire chips was utilized towards curtailment of structural deformation by using such material as a cushion behind rigid and massive retaining structures such as quay wall as shown in Fig. 14. The protective cushion layer provides flexibility, and thereby stability to the structures during earthquakes by means of energy absorption. This has been proved through the results of a large scale model test of the technique in underwater condition (Hazarika et al., 2008). The results of the tests are testimony to the versatility of the technique illustrated in Fig. 14.

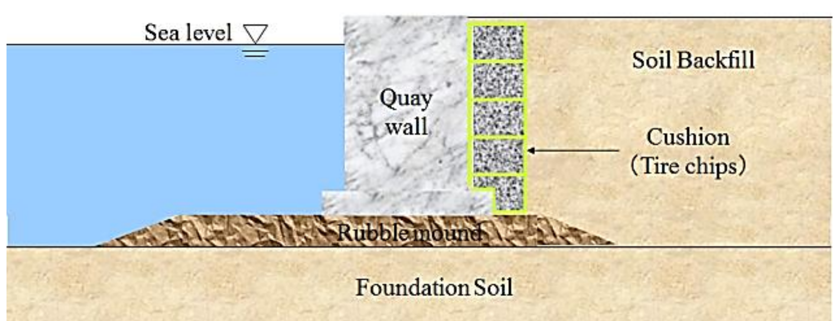


Figure 14 Tire chips cushion as seismic buffer (Hazarika et al., 2008)

In the test series conducted by Hazarika et al. (2008), the cushion was made up of pure tire chips, implying a standalone application of TDGM. However, in order to minimize the amount of tire chips to be used in making the cushion, it can be considered

to mix some percentage of sand with tire chips by enclosing the mixture inside geotextile bags, and then placing those behind the structure. This kind of mixing and confining technique not only saves the amount of tire chips/tire shreds to be used in a project, but also reduces any unwanted vertical settlement due to vertical load coming from the structure on the backfill. In addition, mixing and confining of the materials makes the execution easier and faster.

3.7. Tires Chips as Vertical Drain

Use of tire chips as drainage-accelerating materials (tire chips drain) to prevent soil liquefaction was first proposed by Yasuhara et al. (2010). Another technique is proposed by Hazarika (2012), where in addition to the vibration absorbing cushion layer described before, vertical drains made out of tire chips are installed in the backfill of gravity type retaining structure as a liquefaction preventive measure (Fig. 15).

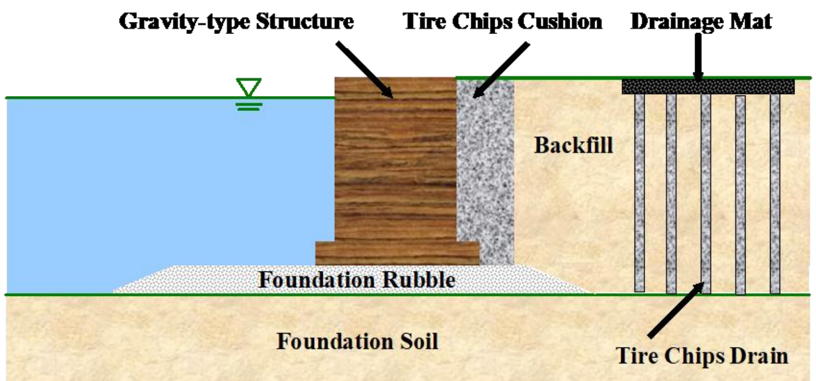
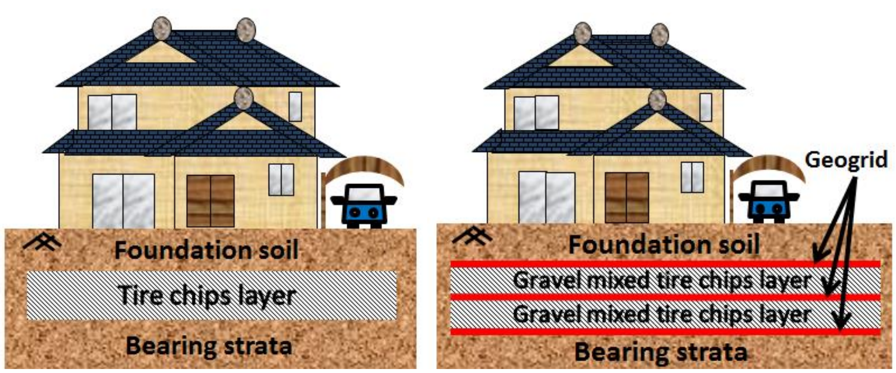


Figure 15 Tire chips as cushion and drain in seismic application *(Hazarika, 2012)*

4. COMPOSITE APPLICATIONS

4.1. Sand/Gravel Mixed Tire Chips as Isolation Layer

Tire chips or tire chips mixed sand/gravel also can serve the dual purpose of base isolation and liquefaction prevention of building foundation. Hazarika et al. (2009) proposed a low-cost liquefaction prevention method that can reduce building damage by using recycled tire materials (tire chips) under the foundation of residential building. A conceptual diagram for the method is shown in Fig. 16a. However, tire chips have high compressibility, and thus the above technique is expected to have disadvantages, which include the occurrence of differential settlement and insufficient bearing capacity. Therefore, as a countermeasure, it was proposed to reinforce the tire chip layer by adopting a dual approach: mixing gravel with tire chips and laying geogrid within the gravel mixed tire chips layer, as shown in Fig. 16b (Hazarika and Abdullah, 2015). Such a measure can suppress differential settlement and improve the bearing capacity of foundation soils. This type of measure effectively utilizes the functions of two dimensional geosynthetics such as geogrid and three dimensional geosynthetics such as tire chips/tire shreds. The concepts and functions of the two-dimensional and three dimensional geosynthetics have been enunciated by the International Geosynthetics Society (IGS, 2009).



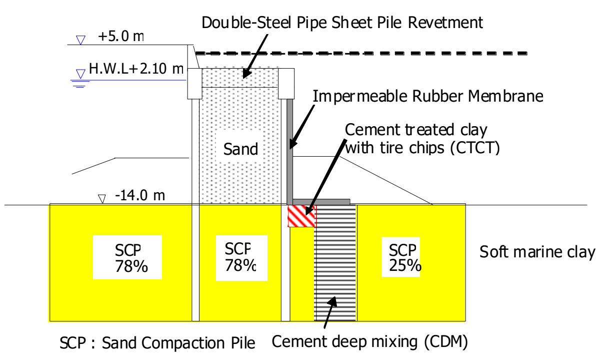
(a) Pure tire chips layer (b) Gravel mixed tire chips layer with geogrid

Figure 16 Tire chips as base isolation layer

4.2. Tire Chips Mixed Cement Treated Clay in Waste Disposal Barrier

One important aspect in designing barrier for marine waste disposal fill is to minimize barrier breakage in the event of serious deformation of the revetments. Cement treated soil is a promising sealing material for disposal fills due to its low permeability. It is generally known that cement treated clay (referred hereafter as CTC) shows improvement of shear strength in comparison with soft clay. However, cement treated soil is brittle in nature, and therefore, it cannot follow the revetment deformation. As a result, potential crack propagation is likely to affect the permeability of such material, and thus the sealing effect. An effective means of improving the ductility and maintaining the low permeability of CTC is to add tire chips to it. Research by Yasuhara et al. (2004) has demonstrated that the toughness of CTC could be improved by adding shredded tire chips. Cement treated clay with tire chips (referred hereafter as CTCT) possesses high shear strength and toughness, and therefore, can be used as a barrier material for revetments in a controlled waste disposal facilities constructed offshore.

Fig. 17a shows the cross-section of revetment of coastal waste disposal site (Shinkaimen-disposal site) in Tokyo bay, Japan in which CTCT was used to prevent anticipated deformation (Mitarai et al., 2006). The revetment was constructed with double steel piles, and its foundation soil was stabilized by sand compunction pile (SCP). CTCT was placed between the steel piles and the ground improved by cement deep mixing (CDM). CTCT was prepared by mixing dredged clay (from the construction site), Portland cement and tire chips. The length of the improved area in this execution work was about 83 m. Nearly 800 m^3 of CTCT was used in this construction. The amount of tire chips consumed (Fig. 17b) in the project was about 80 ton. Since, an ordinary passenger car tire yields about 5 kg of tire chips, which means that about 1600 pieces of passenger car tire could be recycled in this construction work, implying a tremendous contribution towards sustainable construction.



(a) Cross sectional view

(b) Ships carrying tire shreds to the site

Figure 17: Tire chips mixed treated clay in waste disposal site (Mitarai et al., 2006; Yasuhara et al., 2004)

4.3. Tires Shreds as Vibration Mitigating Materials

Takemiya (2007) described a technqiue in which tire shreds were used as energy dissipating fills inside pre-cast concrete cell walls to mitigate traffic induced vibration. For the targeted frequency range, the method is seen to very effective in mitigating vibration as compared to conventional wave barriers.

5. CONCLUSIONS

Continuous increase of waste tires every year is placing a huge burden on our environment. Although recycling of tires has been adopted in various ways, low carbon generating material recycling process needs to be prioritized. This paper introduces some of the Japanese initiatives towards applications of waste tires and waste tire derived materials in geotechnical constructions. Trends of such applications in the recent years is not limited to the environmental preservation, but also disaster mitigation and cost reduction in geotechnical construction. With rapid industrialization and economic growth of many emerging economies of the world, waste tires recycle is going to be a major issue from environmental point of view. Establishment of the proper design procedures and environmental guidelines applicable to local conditions of those countries is expected to provide a new thrust not only to the scientific and technological fields, but also to the environmental and cost performance aspects.

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